Potential Impact of the Circular Economy Concept in Maritime Transport

A White Paper

Cents
Circular Economy Network+ in Transportation Systems

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1. Background

Circular Economy

The idea of a circular economy (CE) grew out of the traditional linear economy, wherein goods are made from raw materials, sold to end users, and thrown away when their economic life is over.

The circular economy approach is based on reusing existing materials instead of raw materials. By doing so, the closed-loop approach reduces waste and energy requirements. CE has several concepts generally known as re-terms or 6R, such as reduce, redesign, recover, reuse, remanufacture and recycle (Gong et al., 2020).

The circular economy strategy seeks to maximise value retention and extraction while optimising resource use through these principles. Resources recovered or maintained via these activities reduce the consumption of raw materials, labour, energy, and capital while reducing the environmental effect caused by industrial processes, such as greenhouse gas emissions. With 6R, which covers every step of a product's lifespan, from the design phase to the end-of-life phase, the circular economy idea brings a range of advantages. CE advocates closed-loop recycling solutions, in which the material is returned to the original identical product system. Remanufacturing, for example, requires a reverse logistics system to complete the material cycle.

Among all end-of-life techniques (6R), remanufacturing is often described as the ultimate recycling. That's because remanufacturing is more efficient than recycling, which wastes many resources and time. Recent research confirmed similar advantages of using a diesel engine cylinder block, indicating an 88-99% decrease in energy usage, along with 39% cost savings in the new cylinder block manufacturing (Afrinaldi et al., 2017). It is known that there are high-quality products in the market which can be remanufactured several times (for some, up to seven cycles), resulting in significant energy and raw material savings. As a result, it is fair to call remanufacturing a crucial part of the circular economy since it allows all parties involved to improve their long-term sustainability.

Even though the 6R principles of the CE are critical for all transport modes, this whitepaper will focus on the circularity of maritime transport. Maritime is the most energy-efficient transport mode, but it still has a lot to improve to draw a circular industry portrait. The next part will focus on the maritime industry's internal dynamics and future potential in terms of circularity.

Maritime Transport

Maritime transport is the backbone of the global economy since it moves over 80% of the world trade by volume, which is predicted to triple by 2050 (UNCTAD, 2022b).

However, with the increasing demand for the maritime industry, the emissions caused by the industry will also rise across all stages of the life cycle. Recent estimates show that 10-15% of SOx and NOx emissions come from shipping, and that number will go up a lot by 2050 unless serious steps are taken (Bjerkan & Seter, 2019; Zis & Psaraftis, 2019). Currently, the maritime industry is aiming to reduce its operational global greenhouse gas (GHG) emissions, and going through a transition period to meet the demands of the UK, EU and IMO on the net-zero targets. Therefore, the industry has pledged to lower its operations' GHG emissions by 50% by 2050 (International Maritime Organization, 2018; Milios et al., 2019). Academia is focused on lowering emissions and utilising renewable and green fuel sources in the maritime industry to replace fossil fuels. The actions to meet this deadline must be taken now, considering fairly long lifespan of commercial ships. As there are over 100,000 merchant vessels worldwide (UNCTAD, 2022a), the environmental impact will be tremendous. In addition to the replacement fuel sources, the industry will need to address sustainability through circularity principles from shipbuilding to ship recycling.

Currently, the shipbuilding industry generates 42,600 jobs and provides £2.8 billion to the UK economy (NSO, 2022). The shipbuilding operations mainly involve hull construction, outfitting, commissioning, testing and delivery. Even a basic cargo ship is equipped with valuable onboard components such as the main engines, auxiliary engines, compressors, pumps, navigation equipment, electronics, computers, and so on. Today, the average design life of cargo ships is in the 20–25-year range. For instance, Figure 1 shows the average age of merchant fleet, and Figure 2 illustrates the average demolition age on top of the fleet age of containerships. The onboard components are also designed to serve through a ship's lifespan—provided the necessary preventive maintenance is regularly carried out.

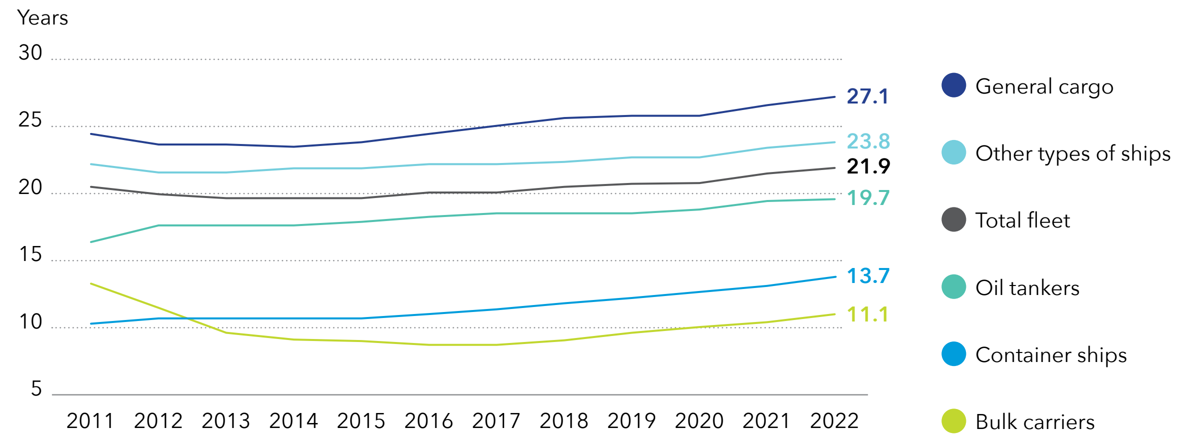


Fig.1. Average age of merchant fleet, 2011-2022 (Clarksons, 2022; UNCTAD, 2022b)

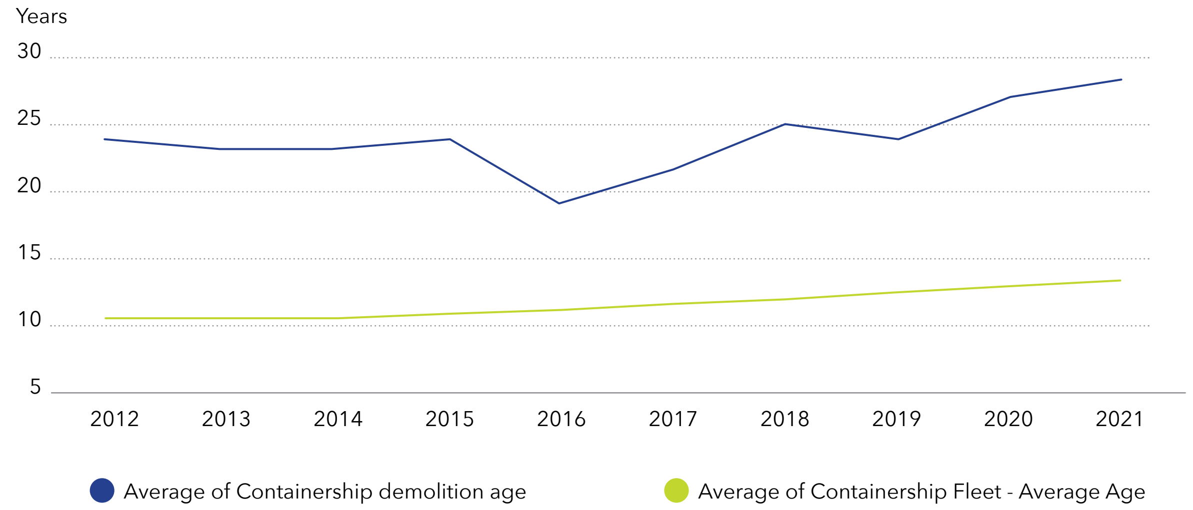


Fig.2. Average fleet age and demolition age of containerships (Clarksons, 2022).

Unfortunately, the maritime industry lags behind other modes of transportation in terms of circular economy, but this also means that there is significant potential to be realised (Okumus et al., 2022). Overall, the (circular economy aspect) link between life cycle stages is missing in the maritime industry for several reasons, including but not limited to lack of awareness in the industry, regulatory barriers, long-lifetime of the marine assets, lack of the reverse supply chain and the poor end-of-life practices.

Although the average life is 25 years, we frequently see much younger ships sent to scrapyards for various reasons. Some shipowners and operators mention that after 7–8 years, they have difficulties chartering their vessels due to industry competition and the insurance providers' policies on premiums. Therefore, most ship operators tend to renew their fleets earlier than is physically required.

Considering this picture from an engineering perspective (i.e., excluding commercial or business management strategies that may affect such decisions), every ship and its onboard components are sent to waste much earlier than their end-of-life. That is a huge waste of natural resources (e.g. O2, water), raw materials, manufacturing energy, and heavy industry labour. This also triggers considerable carbon emissions in the new ship production process to fill the gap.

Most of the valuable onboard components are underutilised at their end-of-life phase. Except for a few locally used component sales, there are only a few structured circular economy principles, such as the repurpose-reuse-remanufacture (Okumus et al., 2022). Therefore, with the current capabilities of the ship recycling facilities, once valuable components are taken from vessels, they lose their potential for restorative circular economy principles.

2. Methods and materials

This study examines the maritime industry and potential circular economy practices in the industry.

To do that, the authors have carried out three workshops, an online webinar in December 2022, and two face-to-face events in January and February 2023.

These structured workshops focused on applying circular economy principles to the maritime industry. There were participants from all over the world belonging to different stakeholder groups in the maritime such as ship designers, building and repairing shipyards, ship owners/operators, classification societies, OEMs, regional and international authorities, academia and so on. The steps outlined in Figure 3 are used in this research to accomplish the research objectives.

Step 1 involves the brainstorming phase, where authors exchanged ideas to create a framework for the maritime circularity concept. As a result, the separation of onboard equipment and overall vessel level circularity idea is put forward and adopted. Section 3 dives into this perspective's details and clearly explains both levels. Steps 2 and 3 are the findings of three workshops, presented in Section 4. The last step in Figure 3 is about the solution strategies where authors compiled literature reviews, stakeholder meeting notes and workshop results to develop ways to progress in maritime circularity.

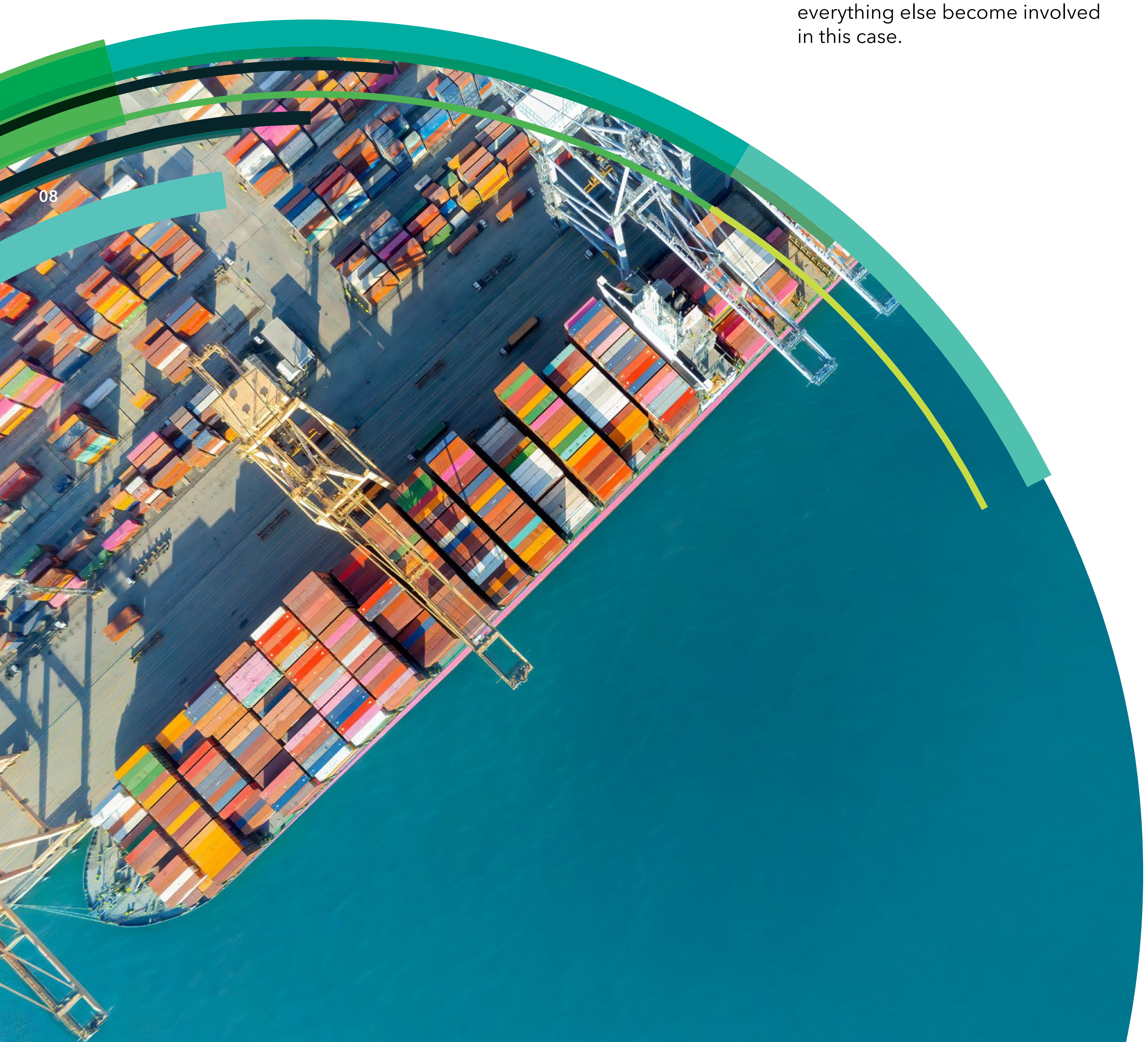
Fig.3. Adopted research steps.

3. Maritime Circularity

Overall, it is safe to say that the maritime industry is far behind in circular economy practises compared to other transportation industries.

Even though significant steel recycling practices are going on, there are no structured advanced circular economy practices such as repurposing, remanufacturing, or reusing at the end-of-life stage (Okumus et al., 2023). Maritime circularity can be examined at two levels: the first is the onboard equipment level, and the second is the overall ship level.

On the equipment or component level, the most valuable items onboard ships are main and auxiliary engines. Therefore, many things are in common with the power generation industries in this segment, as power generation companies are the main suppliers of such equipment. On the other hand, things become more complex regarding the overall ship-level circularity. That is because, apart from the onboard equipment, the structure (a steel hull), accommodation facilities, and everything else become involved in this case.



Component level circularity

There are various valuable components on board commercial vessels.

In particular, the engine room and bridge consist of equipment such as main and auxiliary engines, hydraulic pumps and motors, compressors, navigation equipment, purifiers, electronics, computers, etc. Restoring these parts' value at their end-of-life depends on several factors, which can be listed as the original design by their OEMs, the design-for-remanufacturing (DfRem) philosophy, spare part availability, and the updatability of the original design. Most of these parts can be remanufactured, refurbished, or reused in the right conditions rather than directly recycled. Recycling is the lowest form of circularity because most of the value-added labour and manufacturing energy are lost in the process. From the circularity aspect, more advanced alternatives to recycling are remanufacturing, refurbishing, repurposing, and reusing.

There are excellent examples from other transportation and power generation industries regarding used component recoveries. For instance, for engine parts such as crankshafts, engine blocks, cylinder heads, turbochargers, and alternators, there were from 29% to 98% raw material savings, from 21% to 55% manufacturing energy savings, and when combined with logistics aspects, from 5% to 52% less environmental impact and emissions recorded (Koehler, 2021).

These savings clearly demonstrate the potential benefits for the mechanical parts, and refurbishing options bring substantial benefits for the electronics and computers.

Engines are the most valuable onboard components on cargo ships. A rule of thumb in the initial design stage, or rather an educated guess in most cases, implies that around one-third of the ship acquisition cost is related to main and auxiliary machinery. When this is the case, restorative circular economy applications for marine engines become extremely important. At this point, it should be noted that most engine manufacturers (OEMs) serve different industries apart from maritime. For this reason, although there is not such an intense demand in the maritime sector, many manufacturers have brought themselves to a certain level in terms of circular economy practices.

Regarding a maritime-specific study, a case study from the literature investigates a high-speed main engine remanufacturing operation. The case study reveals that engines can be remanufactured for half of what a brand-new alternative would cost and provide brand-new performance and reliability (Okumus et al., 2023). In fact, as a result of a set of comprehensive restorative processes and tests, the engine was found to be on par with its brand-new alternative, which resulted in an extended warranty allowance from the OEM for that engine.

Further successful marine-focused case studies should be conducted. Other high-potential onboard components include hydraulic equipment (pumps and motors), compressors, engine subcomponents, navigation equipment and electronics. The authors believe further case studies for these components will help in the circular transition within the maritime by increasing awareness and promoting the potential financial, environmental and social benefits.

A key concept in order to spread these benefits and make them the norm of the sector is the reverse supply chain. Remanufacturing and other advanced circular economy principles require core parts back to initiate the restorative processes. Therefore, the "core collection step" is essential in closing the material loop and achieving a circular flow. There are different strategies and technology solutions to promote core collection or reverse supply chain in general. During the workshops, the maritime stakeholders found asset-tracking technologies to be one of the key elements since they would enhance the reverse supply chain. Other important circular economy enablers mentioned are cultural change, increasing awareness, end customer engagement, digitalisation and upskilling the workforce.

Ship level circularity

Circular economy principles affect the whole lifecycle of ships and all stakeholder groups throughout the vessel's lifespan. Figure 4 represents all stages of a commercial vessel and responsible stakeholders at each step, coupled with the circular economy principles.

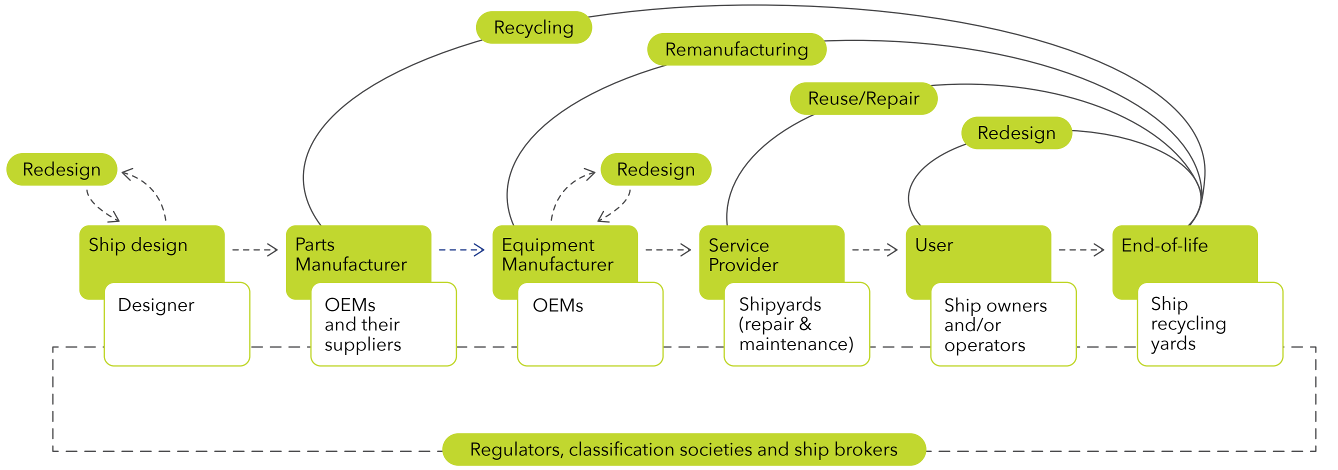


Fig.4. Circular economy principles and maritime stakeholders, from (Okumus et al., 2022).

The redesign step is the most important principle for ship-level circularity as it brings the possibility of more durable product design and increased operational lifespan. The circular economy concept aims to minimise raw material needs, manufacturing wastes, energy consumption, and emissions by extending useful life. However, ship-level circularity is much more complex than equipment-level practices as structural integrity comes into play.

Currently, the average design life of cargo ships is in the 20–25-year range. From a naval architecture perspective, the limiting factor is usually the structural integrity or hull strength. And from the commercial point of view, profitability, competition, and operational costs are critical constraints.

Naval architects have to deal with challenges like corrosion and fatigue to ensure the safe operation of vessels. It is known that the detrimental effects of fatigue cracks and corrosion worsen over time. Therefore, extending the design life requires some essential changes compared to today's standards. Obviously, a stronger design can be achieved by using either standard shipbuilding steel in larger amounts or more advanced steel alloys, which are subject to metallurgical and materials engineering.

Apart from a stronger design approach, let's say that for reaching 50 years of operational life, ships should be equipped with advanced technologies such as active corrosion monitoring and hull stress monitoring systems. These technologies utilise various sensor types to detect corrosion and measure on-time hull stress constantly, which may act as a crucial indicator of hull health and keep everything under control before a serious deformation forms. That way, a stronger-designed hull can cope with hogging and sagging motions and every other impact that long years can throw at it.

The stakeholder workshops revealed global standards and regulations in the maritime industry as one of the strengths of the industry. However, the common idea was that there is a need to take a step forward towards green design regulations to promote a circular economy transition. Another finding was the need for a holistic approach to emissions. Lifecycle carbon reduction should be included in future calculations. In particular, manufacturing emissions should be calculated and recorded in a dedicated section.

Decarbonisation and circular economy connection

Decarbonising the lifecycle and circular economy integration is also significant for the future of the UK shipbuilding industry, as the major shipbuilding countries globally have already started their efforts in this area. For example, South Korean yards have already started their research and innovation activities to reach carbon neutrality during shipbuilding operations by 2050 (John Yum (SFOC), 2022; Mandra, 2021). Hyundai Heavy Industries, Samsung Heavy Industries, and four different shipyards have formed a committee to achieve this aim. Their plans include using more renewable fuels and tailor-made energy monitoring systems to reduce shipbuilding operations. The carbon-neutral pledge of the Korean yards is likely to pose an inevitable challenge to global shipbuilders, including the UK Shipbuilding industry. Therefore, timely response and preparation by the industry are required.

The transition to green fuel in the maritime industry significantly changes the sector. New fuels mean new engines or power generation technology in general, which require new fuel storage and bunkering systems. Considering decarbonisation awareness amongst all other transportation industries, such as automotive, rail, other land transportation, and aviation, undoubtedly, there will be a high demand for these environmentally friendly fuel solutions. At that point, the authors cannot emphasise the importance of ports enough, as they have substantial potential to become green energy hubs for multimodal transportation sectors. Meetings and workshops held for this study show that some important UK ports are interested in becoming future energy hubs.

On the other hand, the maritime industry faces several uncertainties regarding future fuels. Currently, there is not consensus or alignment among maritime stakeholders to stick to a fuel source or strategy. Since this transition requires intensive investments, there is little room for amendments after the start line. Stakeholder groups look at each other and try to observe what others are doing and what would be the most advantageous choice for them. Authorities and regulatory bodies might act as catalysts by addressing their future strategies regarding green fuel sources such as hydrogen, ammonia, and methanol.

4. Findings

In this section, the main outputs of the maritime stakeholder workshops are presented. The conversations from the stakeholder engagement events are summarised in a critical gap analysis and a SWOT analysis.

Gap Analysis

Figure 5 illustrates the current gaps raised by the stakeholders in the workshops. According to the participants from the industry, the missing steps towards a more circular maritime industry can be defined as:

i. **Industrywide alignment:** A drawback is caused by the potentially conflicting goals of different stakeholder groups. This can be overcome by defining the responsibilities and roles of each stakeholder group.

ii. **Clear expectations and KPI:** There is a need to define what each stakeholder group expects to achieve and sustain a circular economy as an industry. Moreover, there is a lack of KPIs or metrics to measure the sustainability or circularity of the maritime assets/components.

iii. **End customers' awareness:** Awareness levels of cargo owners, charterers (end customers in general), and insurance companies regarding the circular economy should be increased. Their current perception creates a large gap as they tend to apply vessel age limitations which results in capable ships standing in idle and underutilised, eventually sent to a scrapyard.

iv. **Economic aspect:** Demonstrating the economic impact of the circular economy on the whole-lifecycle cost of onboard equipment and overall ships is another issue that needs to be addressed. Case studies and feasibility reports can help with this gap.

v. **Quality and certification:** Equipment quality and reliability are other steps on the way, as remanufacturing and reusing principles of the circular economy might create misleading ideas, especially for stakeholders with low awareness levels.

Moreover, practical examples and case studies from other industries might help close the above gaps. Also, incentives from policymakers to promote remanufactured components might improve adoption rates of such circular practices.

Fig.5. Gap Analysis

SWOT Analysis

Further to the gap analysis, a SWOT analysis was conducted with the participants during the workshop as a brainstorming session to explore a broader perspective.

As shown in Figure 6, the analysis was focused explicitly on 6R principles for valuable onboard equipment. Brief outputs of the analysis can be listed as follows.

The maritime industry is heavily regulated, so existing global standards and KPIs that the whole industry applies can be listed as one of the evident strengths. Circular economy principles can be applied to maritime systems such as ports, shipyards, recycling facilities, OEMs, etc. Moreover, major ship owners are interested in repositioning and reusing their assets, and they can lead the way for the industry. The advent of emission-free green engines brings another opportunity to adopt the "design for remanufacturing" concept. For instance, ammonia engines are just around the corner and are expected to be commercialised in 2024 (Lindstrand, 2023). Therefore, the benefits of circular economy and remanufacturing onboard equipment gain more importance than ever.

However, the maritime industry also contains several weaknesses towards the circular economy. The biggest one is that the stakeholders do not understand the circular economy. A lack of awareness and industry-wide negative perception results in a challenging transition. Also, the industry cannot respond quickly due to the slow-updating nature of global standards, policymakers, and regulators. Apart from that, alternative fuels are not available on a commercial scale, and when they are, the storage of these fuels will be another issue.

As for the opportunities, firstly, there is the huge potential value of onboard equipment and materials, which can be tracked with a potential material passport system. There is a range of future green fuels, each with different pros and cons. Most maritime OEMs have experience with the circular economy from other industries since they serve multiple sectors such as power generation, defence, transportation, etc. And the demonstration of the circular economy benefits through similar industry benchmarks and maritime case studies is a remarkable opportunity. In terms of UK benefits, creating this approach and understanding the maritime industry would create a need for expertise and a skilled workforce (for remanufacturing, designing and reconditioning marine assets). This will further create environmental, social, and financial benefits and put the UK in an EU-leading position.

On the other hand, threats include the lack of policies, standardisation, and re-certification for remanufactured components. When governments change their policies often, it causes mistrust among long-term investors, such as ship owners or operators. There is a wide range of products and options in the market, but maritime stakeholders are not settled on circular economy and decarbonisation strategies. At the same time, the newer vessel preference of insurers and end-customers (cargo owners) puts the overall industry in a difficult position regarding environmentally friendly manufacturing practices and sustainability. Moreover, long distances between production (shipyards for vessels and factories for onboard equipment) and dismantling facilities (ship recycling yards) pose another threat to circularity. Lastly, the processes in the dismantling facilities are more focused on the recycling of the items rather than salvaging or extending the life cycle. This is mainly due to a lack of awareness, which can be overcome with an industry-wide training campaign.

SWOT ANAYLSIS: 6R principles for valuable onboard equipment

Strengths

- Global standards what whole industry can apply
- Global KPIs
- Major ship owners can lead the way for the industry
- Shipowners are enthusiastic about re-positioning and repurposing their assets.
- Emission free ammonia engines are coming in 2023 and 2024
- Applicability of CE principles to different systems: such as ports, yards, recyclers, OEM etc.

Weaknesses

- CE is not clearly understood by the maritime industry.
- Ship operations are in the mercy and regulations.
- Policies need to be improved. As at the moment ship owners can not use existing circular economy principles.
- Alternative fuels are not available for a commercial scale. This is affecting the current new shipbuilding activities.
- Limited space for fuel tanks on vessels.
- Propulsion technologies are not ready for alterantive fuels (e.g. engines).
- Investment costs are huge, thus the stakeholders need help in financing and strategy to go forward.
- Data availability and transparency is lacking

Threats

- Lack of universal policies and standarisation
- Lack of consensus between maritime stakeholders and related industries.
- Governments changing their policies causing mistrust on the long term investment.
- Newer vessel obsession of insurers and customers.
- Wide range of products and options exist but maritime stakeholders are not settled on CE & decarbonisation strategies.
- Long lifespan of maritime assets.
- Long geographic distances between production and dismantling facilities.
- Lack of know-how to utilise end-of-life equipment once again by remanufacturing.

Opportunities

- Variety of future green fuels.
- Value of onboard materials and potential 2nd hand use.
- Accountability, material passport: tracking the materials, where it can be used, the real value of the assets.
- Creating green shipping focused jobs (operation efficiency)
- Train people to create awareness in terms of what and how they buy products. That will help decarbonisation.
- Most of the maritime OEMs have expeience from other sectors as well, since they are serving multiple sectors (power generation, defence etc).
- Demonstration of circular economy benefits through similar insdustry case studies to maritime stakeholders.

Fig.6. SWOT analysis

5. Recommended Future Studies

The authors believe that the circular economy concept holds great potential for the maritime industry.

Comprehensive studies on circular maritime or circular shipping are still rare but exist. The authors estimate that in the future, this topic will attract more and more researchers. The workshops conducted within this study's scope proved that the maritime industry stakeholders are interested in finding feasible solutions and a common ground to implement circular economy principles. That simply cannot be achieved without industrywide collaboration and alignment between different stakeholder groups, and the workshops conducted for this study actually proved this fact.

Therefore, any future study regarding circular economy applications in the maritime industry should consider various aspects, including industry-specific stakeholder dynamics, regulatory bodies and standards, world cargo fleets, insurance and reliability requirements, and so on. To make things a little simpler, the critical aspects that should be considered for the future studies are presented in Figure 7.

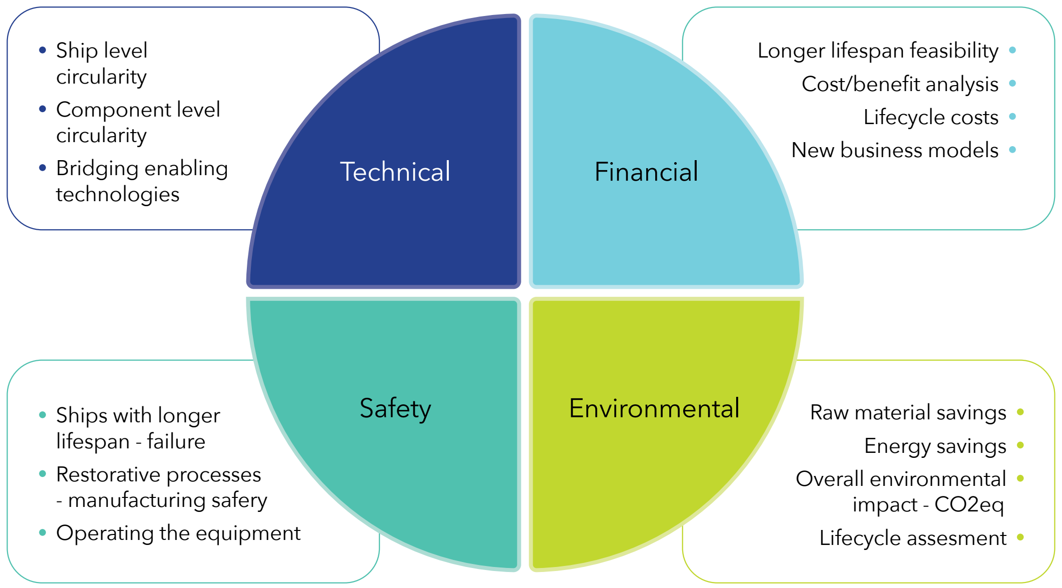


Fig.7. Essential aspects for future studies

The technical aspect includes entire ship-level or onboard equipment-level technical improvements and bridging technologies that an existing fleet can use to increase the overall adoption of a circular economy, which works as a new technology enabler. Anything from a green fuel-powered engine to advanced steel alloys that would improve the lifespan of conventional cargo vessels is covered here. Design-for-remanufacturing and modularity are also important for future designs, as they might improve the industry.

The financial side is probably the most effective aspect of the four. Nothing beats an accurate cost-benefit analysis for industry decision-makers when it comes to a new design or an improvement retrofit for existing assets. Therefore, any study regarding the construction of ships with longer lifespans should not miss the lifecycle cost comparison with existing ways of doing business. Moreover, innovative business models should also forecast proposed scenarios and compare them with current market conditions.

The environmental aspect covers all environmental impacts for every step of the product's life. In accordance with the cradle-to-cradle approach, raw material usage, energy consumption, and emissions are covered here. For the last couple of years, the maritime industry has been focusing on ship operation emissions since that is the most emission-generating stage of a ship's lifespan. However, the focus began to shift as the industry set challenging targets and pledged to significantly reduce operation emissions, putting the shipbuilding phase in the spotlight.

Finally, there is the safety point, which is concerned with the human factors, ergonomics, and reliability factors of any new design, process, replacement, or way of doing business. This perspective can be applied to topics such as the safety aspects of restorative circular economy principles or extending the lifespan of ships.

In terms of the UK focus, the UK needs to take steps to encourage these green solutions by first introducing regulation changes. Incentives can be introduced towards shipping companies, manufacturers, shipyards, and ports that operate environmentally friendly and sustainable manner by reusing, remanufacturing, repurposing their assets. Potential tax benefits for these companies for example, can encourage further companies to adopt such principles.

Moreover, the design principles for UK maritime need to change to enhance the asset circularity, and this can only be done with a holistic approach. UK Centres for maritime circularity in research, production, supply chain and end-of-life support need to be established by the industry stakeholders and government. Separately, stakeholders alone cannot achieve this without structured collaboration.

Switching to green energy sources also brings unique challenges to each stakeholder of the UK maritime sector. In ports, an immense investment and change will be required to supply vessels with electricity (shore power) and bunkering of zero-emission fuels. On the other hand, ships will need a design change to utilise shore power and zero-emission fuels.

Considering the lifetime of a vessel of 25 years, vessels of the future (2025) need to be designed now to achieve the goals of 2050.

Furthermore, the transition to green fuels will also bring a unique challenge of what to do with the existing fleet, and the circularity principles (reuse-remanufacture-repurposing) can act as a bridging strategy for the UK maritime industry. For example, through remanufacturing, these assets can be reutilised in other industries, and even exported to other countries to avoid material waste. Another solution to this challenge can be addressed by implementing technologies such as digital passports, which will enable detailed tracking of the assets and pave the way for more educated end-of-life decisions. A tailored funding programme by UK government can support the industry and academia to work together on these issues and come up with holistic approaches and solutions to these aforementioned research questions and challenges.

Achieving such a transition will create "Green Jobs" in the UK, which will not only create employment but also create a unique skilled workforce for the UK in the long term. This will help re-establishing UK's leadership in the global maritime economy.

6. References

1. Afrinaldi, F., Liu, Z., Taufik, Zhang, H.-C., & Hasan, A. (2017). The Advantages of Remanufacturing from the Perspective of Eco-efficiency Analysis: A Case Study. Procedia CIRP, 61, 223-228. *https://doi.org/https://doi.org/10.1016/j.procir.2016.11.161*

2. Bjerkan, K. Y., & Seter, H. (2019). Reviewing tools and technologies for sustainable ports: Does research enable decision making in ports? Transportation Research Part D: Transport and Environment, 72, 243-260. *https://doi.org/https://doi.org/10.1016/j.trd.2019.05.003*

3. Clarksons. (2022). Shipping Intelligence Network *https://sin.clarksons.net/*

4. Gong, Y., Putnam, E., You, W., & Zhao, C. (2020). Investigation into circular economy of plastics: The case of the UK fast moving consumer goods industry. Journal of Cleaner Production, 244, 118941. *https://doi.org/https://doi.org/10.1016/j.jclepro.2019.118941*

5. International Maritime Organization. (2018). UN body adopts climate change strategy for shipping. In: IMO London.

6. John Yum (SFOC). (2022). Korea's Green Shipping Pathways: The Korean Shipping Landscape and Policy Recommendations for Ocean-Climate Leadership in Shipping.

7. Koehler, D. C. F. (2021). APRA Europe News - 23 August 2021.

8. Lindstrand, N. (2023). Unlocking ammonia's potential for shipping. Retrieved 16/01/2023 from *https://www.man-es.com/discover/two-stroke-ammonia-engine*

9. Mandra, J. O. (2021, 9/04/2021). Top dogs of South Korean shipbuilding industry eye carbon neutrality by 2050. Offshore Energy. *https://www.offshore-energy.biz/top-dogs-of-south-korean-shipbuilding-industry-eye-carbon-neutrality-by-2050/*

10. Milios, L., Beqiri, B., Whalen, K. A., & Jelonek, S. H. (2019). Sailing towards a circular economy: Conditions for increased reuse and remanufacturing in the Scandinavian maritime sector. Journal of Cleaner Production, 225, 227-235. *https://doi.org/https://doi.org/10.1016/j.jclepro.2019.03.330*

11. NSO. (2022). National Shipbuilding Office, National Shipbuilding Strategy. *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1061201/_CP_605____National_Shipbuilding_Strategy_Refresh.pdf*

12. Okumus, D., Gunbeyaz, S. A., Kurt, R. E., & Turan, O. (2022, 14-17 November, 2022). Circular economy approach in the maritime industry: Barriers and the path to sustainability. Transport Research Arena, Lisbon.

13. Okumus, D., Gunbeyaz, S. A., Kurt, R. E., & Turan, O. (2023). Towards a circular maritime industry: Identifying strategy and technology solutions. Journal of Cleaner Production, 382, 134935. *https://doi.org/https://doi.org/10.1016/j.jclepro.2022.134935*

14. UNCTAD. (2022a). Merchant Fleet. Retrieved 20/02/2023 from *https://hbs.unctad.org/merchant-fleet/*

15. UNCTAD. (2022b). Review of Maritime Transport. *https://unctad.org/system/files/official-document/rmt2022_en.pdf*

16. Zis, T., & Psaraftis, H. N. (2019). Operational measures to mitigate and reverse the potential modal shifts due to environmental legislation. Maritime Policy & Management, 46(1), 117-132. *https://doi.org/10.1080/03088839.2018.1468938*

7. Working group members

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Mr Dogancan Okumus
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Mr. Dogancan Okumus is currently in his final year as a PhD researcher and research assistant at the University of Strathclyde's Naval Architecture, Ocean, and Marine Engineering (NAOME) department. With over six years of industry experience, he previously worked at one of the leading engine manufacturers before diving into the academic realm. Dogancan is intensively engaged in research on circular economy practices within the maritime industry, specifically focusing on remanufacturing and value extraction from end-of-life assets. His research ambitiously aims to propel the maritime sector towards sustainability by reducing raw material needs through the application of 6R principles, lowering energy consumption and emissions, and advocating for a transition to green energy sources.

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Dr Sefer Anil Gunbeyaz
Chancellor's Fellow (Lecturer)

Dr Gunbeyaz is a Chancellor's Fellow (Lecturer) at NAOME. Dr Gunbeyaz's main body of research relates to circular economy and sustainability in the maritime domain, trying to address the gaps in the sector by closing the loop and improving the sustainability aspect of the maritime industry. He has been working closely with stakeholders including shipyards, recycling facilities and ports to enhance the sustainability and circularity of the maritime industry.

University of Plymouth

Dr Stavros Karamperidis
Lecturer

Dr Stavros Karamperidis is a Lecturer in Maritime Economics and Head of the Maritime Transport Research Group. Dr Karamperidis is an experienced researcher on maritime economics, logistics and business improvement. He has a strong track record on decarbonisation projects and collaborations on feasibility strategies and how maritime specific businesses could strategically invest and diversify from current operations. He also has several publications related to logistics decarbonisation. Prior to Plymouth he worked for 6 years at Heriot-Watt University as an Assistant Professor in Shipping and International Logistics. Before joining academia, he worked in a range of companies from SME's to large multinationals. Stavros through his roles has a continuous involvement with the industry, thus his involvement in various professional organisations.

Potential Impact of the Circular Economy Concept in Maritime Transport

A White Paper

Circular Economy Network+
in Transportation Systems